Summary of the effects of two years of hygro-thermal cycling on a carbon/epoxy composite material

Composite materials are beginning to be used for structures in the fan section of commercial gas turbine engines. This paper explores the type of damage that could occur within one type of composite material after exposure to hygrothermal cycles (temperature/humidity cycles) that are representative of the environment in the fan section of an engine. The effect of this damage on composite material properties is measured. Chemical changes in the matrix material were limited to the exposed surface. Microcrack formation was identified in the composite material. This damage did not cause a significant reduction in tensile strength or impact penetration resistance of the composite material. Additional data is needed to assess the effect of damage on compressive strength.

SUMMARY OF THE EFFECTS OF TWO YEARS OF HYGRO-THERMAL CYCLING ON A CARBON/EPOXY COMPOSITE MATERIAL

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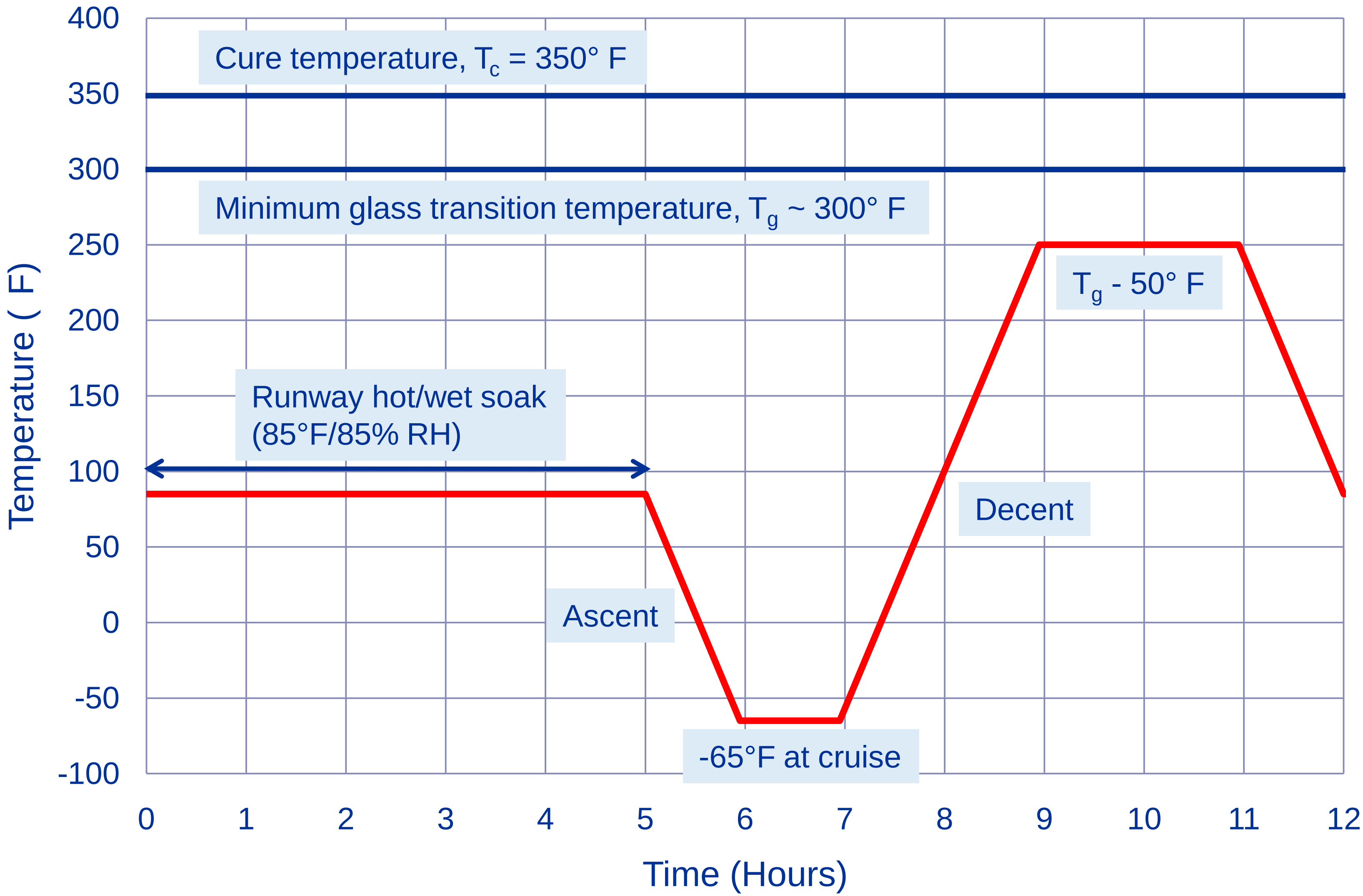
Material fabrication

- Materials
  - Fiber: Torayca® T700S standard modulus carbon fiber
  - Matrix: EPIKOTE Resin 862/EPIKURE Curing Agent W
  - 3 additional materials are currently being aged
- Processing
  - Resin transfer molding (RTM) for both resin and composite
    - Final cure at 350°F (177 C) for 2 hr
    - Resin glass transition temperature, $T_g \geq$ 300°F (149°C)
  - 6 plies, [0°/+60°/–60°] 2D triaxial braid preform
    - 24k axial tows, 12k bias tows
    - Equal fiber volume in all directions
- Cured composite properties
  - 0.125 in thick
  - 56% fiber volume fraction

Hygro-thermal aging cycle



Aging test plan

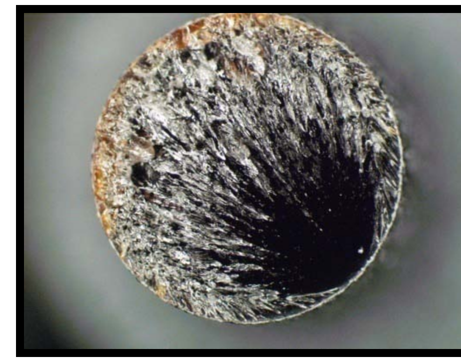
- Resin properties
  - Chemical structure
    - Surface
    - Interior
  - Physical properties
    - Glass transition temperature
    - Volume loss (densification)
  - Mechanical properties
    - Tensile strength and fracture surface
- Composite properties
  - Microcracking
  - Mechanical properties
    - Tension
    - Compression
    - Shear (in-progress)
  - Impact penetration threshold

Color indication of resin aging

Color change in aged tensile specimens

0 54 108 162

Number of cycles



108 cycles

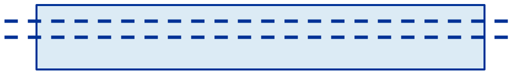
Color change is not limited to the surface

Small changes in chemical structure can cause a large color change

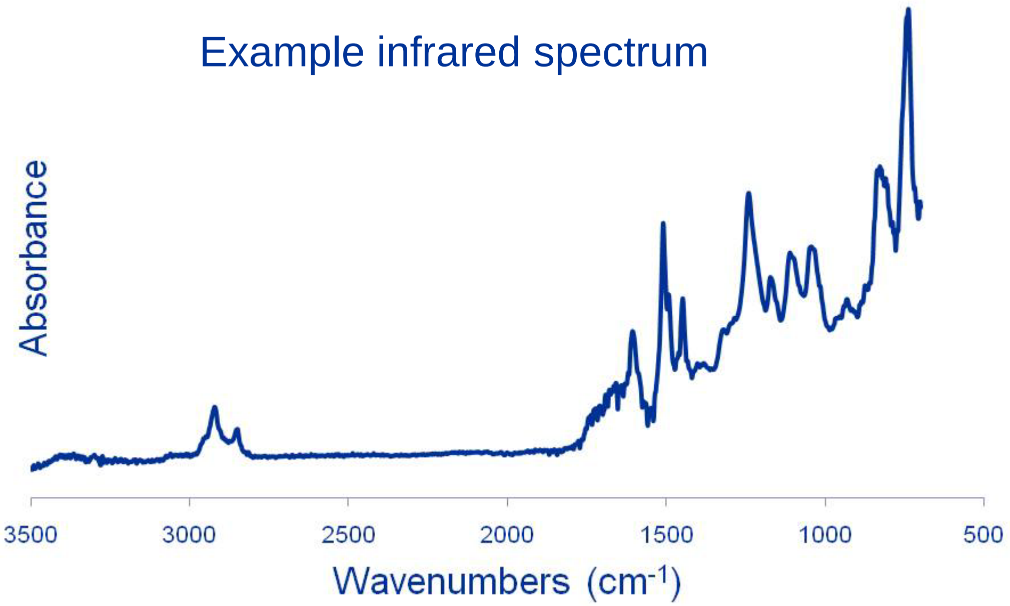
ATR/FTIR test method for chemical analysis

- Infrared spectroscopy
  - Light passing through or reflected from a material is absorbed by each chemical group at a unique wavelength (or wavenumber)
- ATR - Attenuated Total Reflectance
  - Surface reflection technique that probes a surface layer ~0.5 – 5 µm thick
- FTIR – Fourier transform infrared spectroscopy

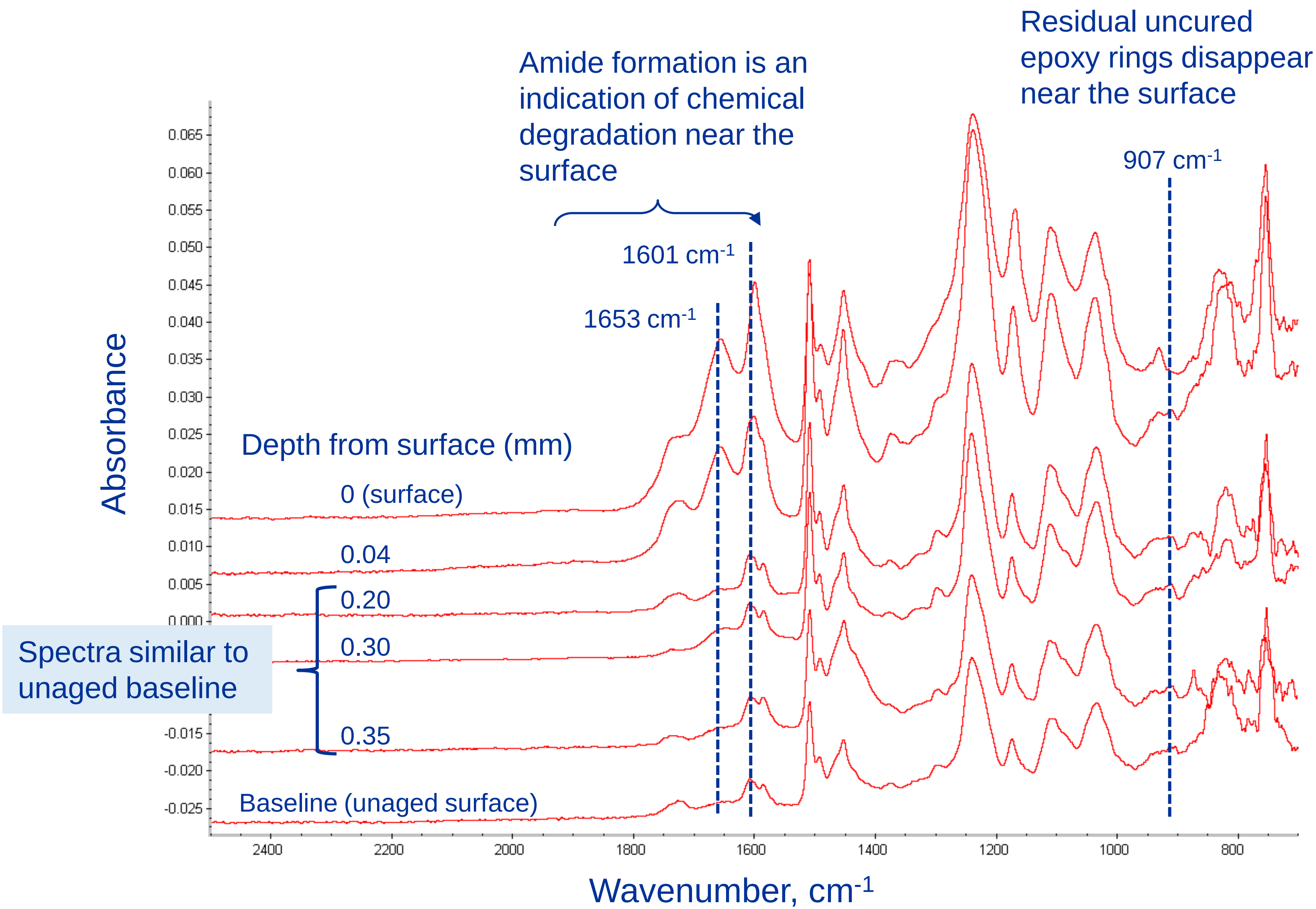
Surface layers are sanded to expose interior material



Example infrared spectrum



FTIR spectra for a specimen aged 271 cycles



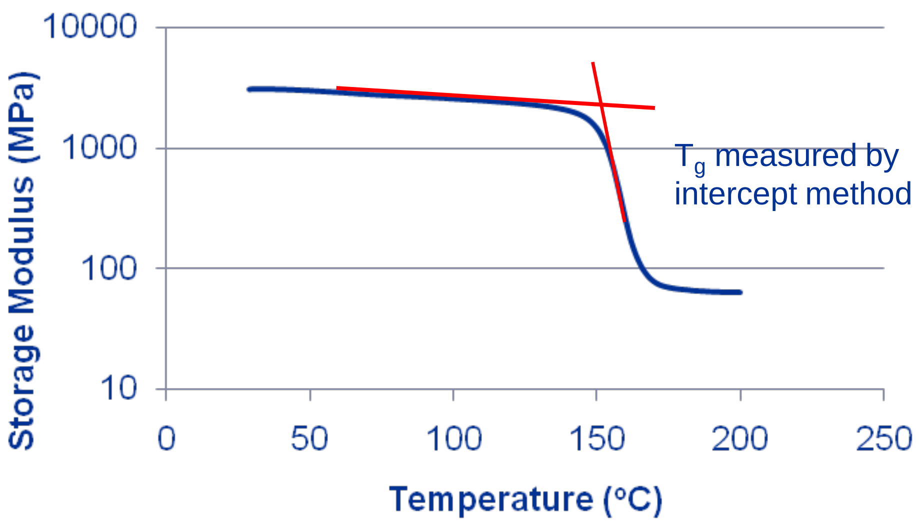
Glass transition temperature test methods

Dynamic mechanical analysis (DMA)

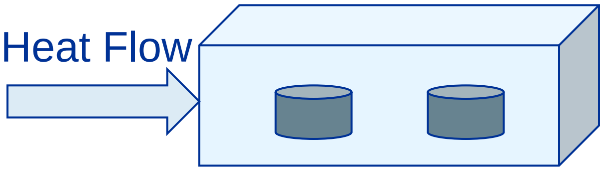
- ASTM D4065-06 – test procedure (resins)
- ASTM D7028-07 – intercept method (composites)

Test conditions

- Single cantilever beam specimen
- Ramp rate = 5 °C/min

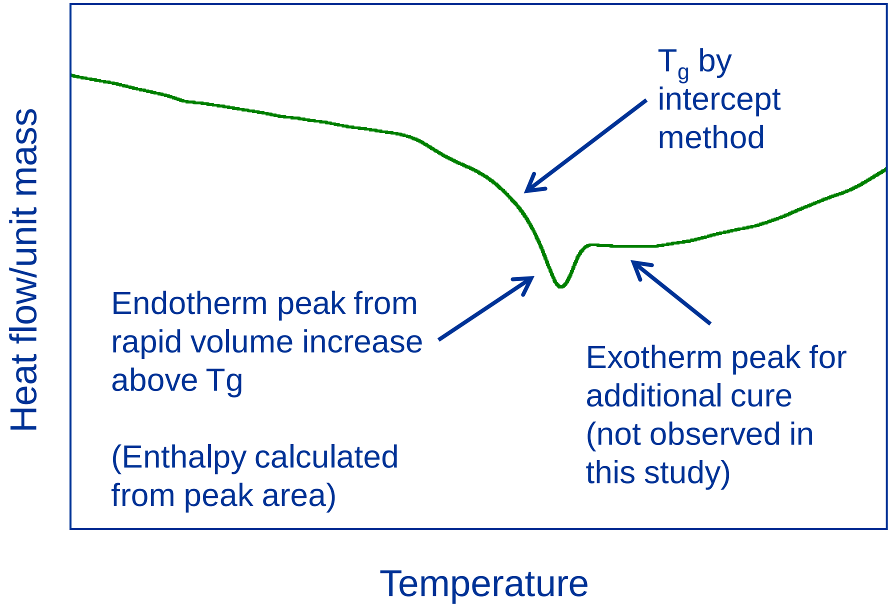


Differential scanning calorimetry (DSC)



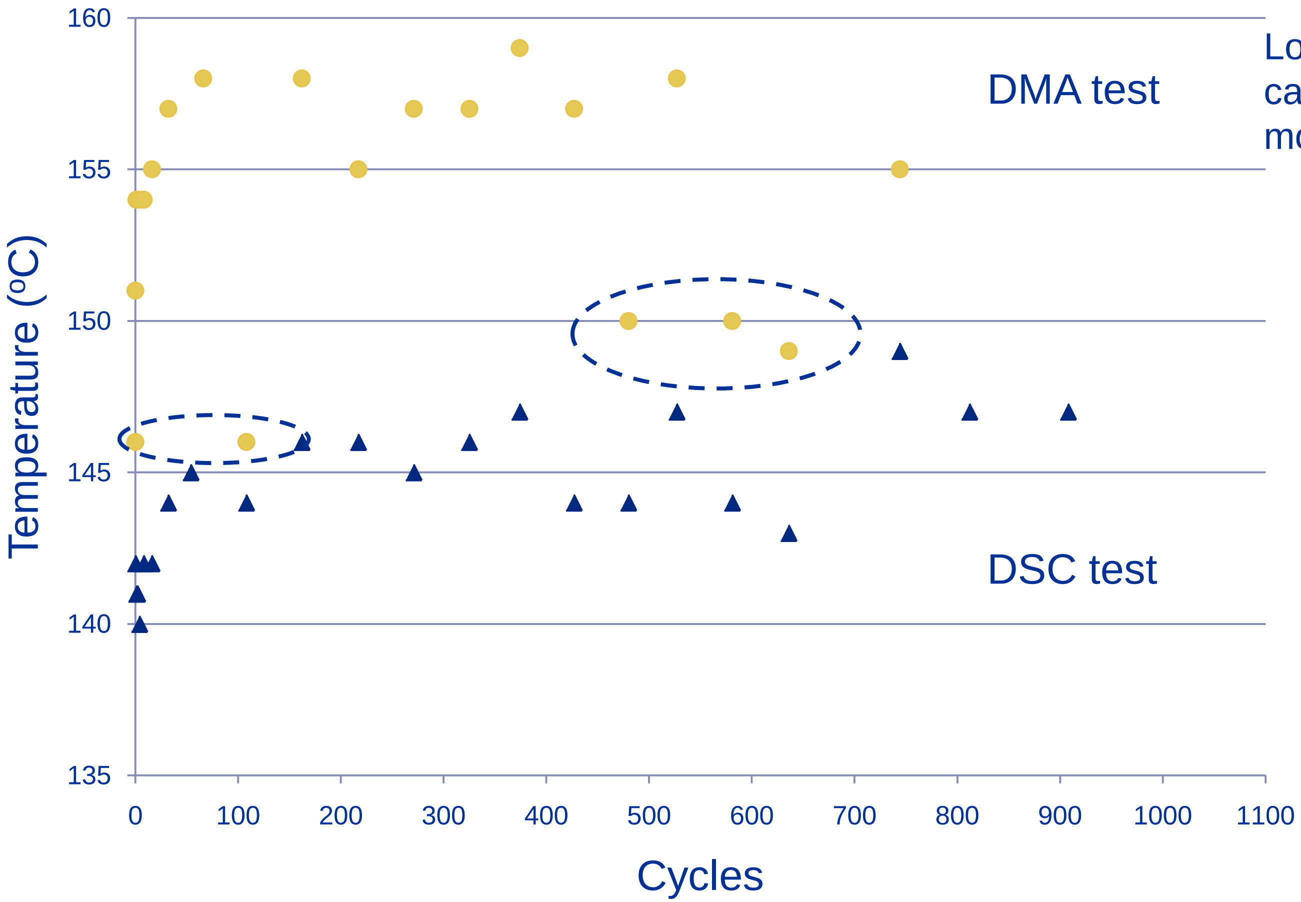
Test conditions

- ~ 5-10 mg specimen mass
- Ramp rate 5 °C/min (modulates with 0.5°C amplitude at 0.025 Hz)



Glass transition temperature

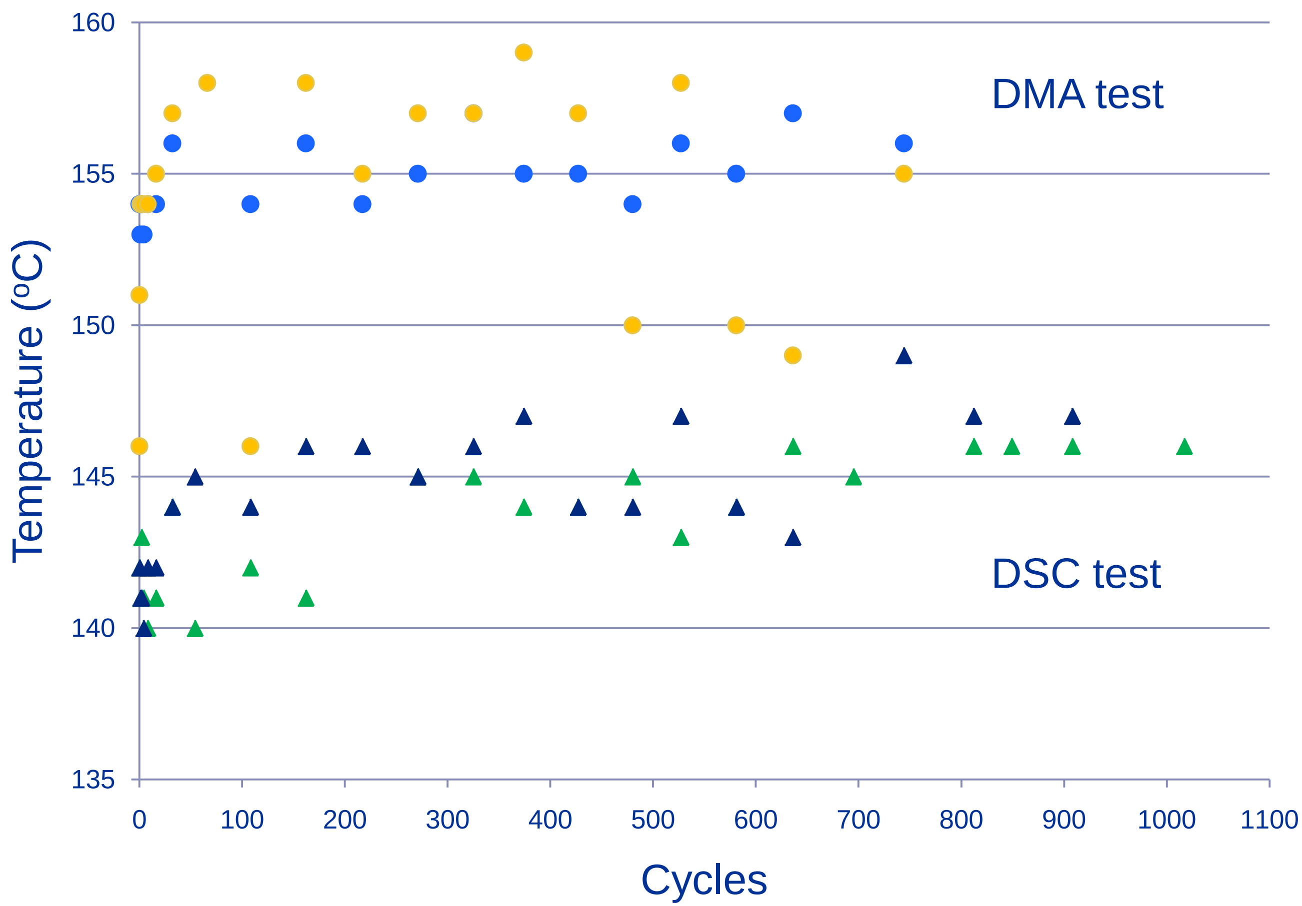
Results for specimens tested monthly during aging



Low values are possibly caused by differences in moisture content

Glass transition temperature

Results for specimens tested monthly during aging



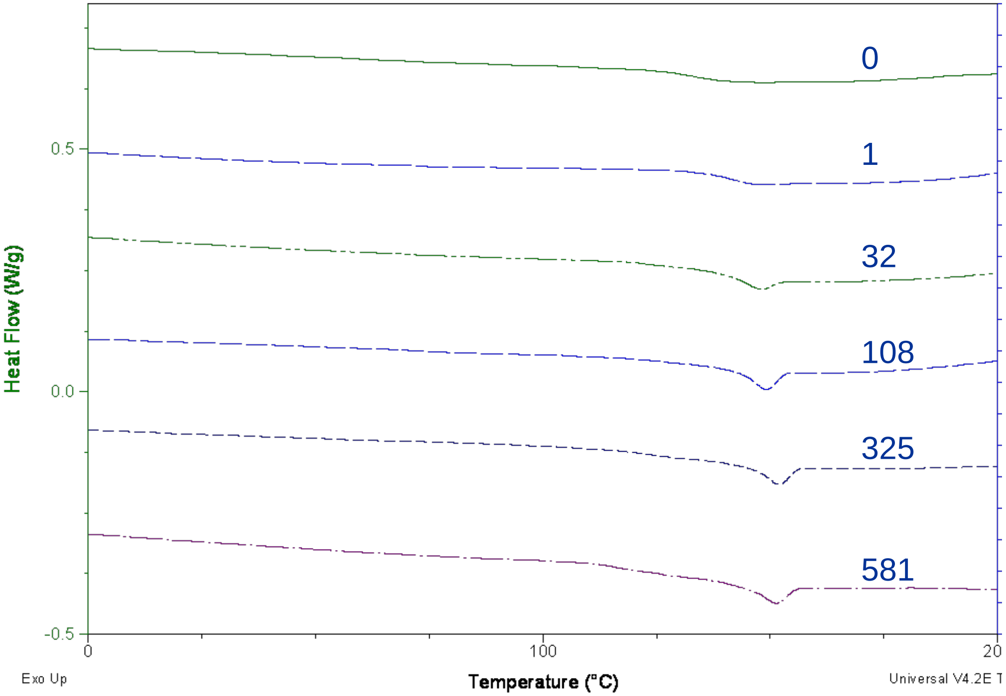
No low values when all specimens are dry and tested consecutively

Tg increases during the first ~50 cycles then remains constant

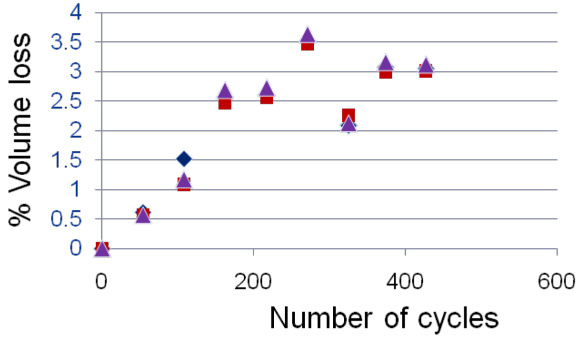
Densification (volume loss)

Growth of the endotherm peak above T_g in DSC curves is a result of densification during aging (also called physical aging)

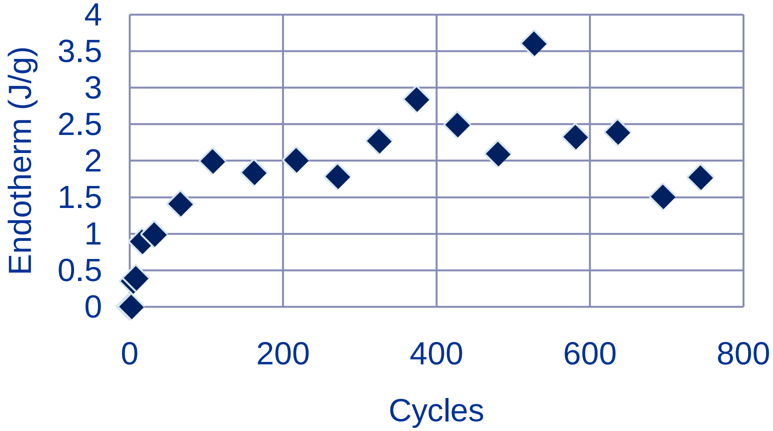
DSC curves measured after various numbers of aging cycles



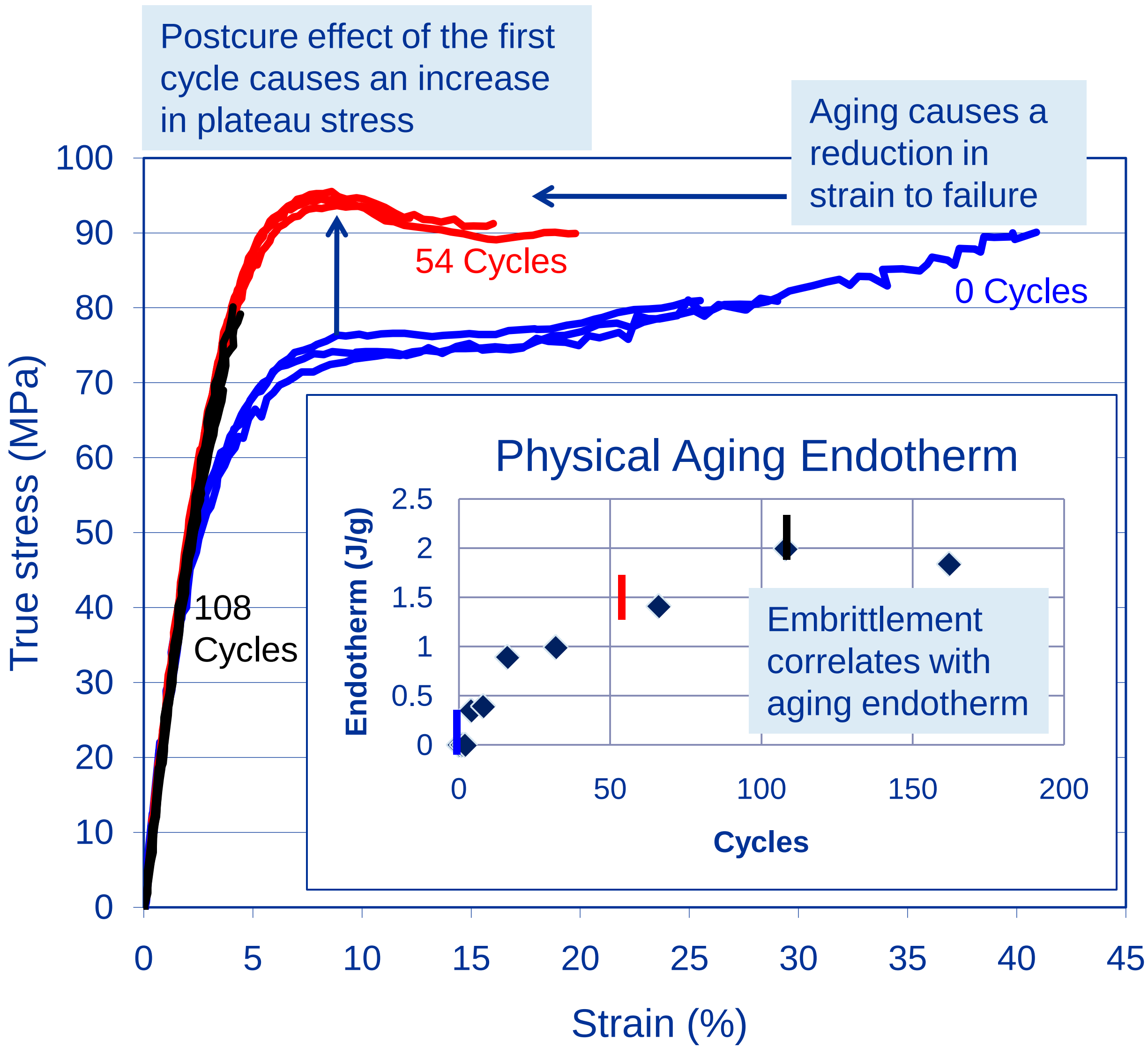
Volume loss



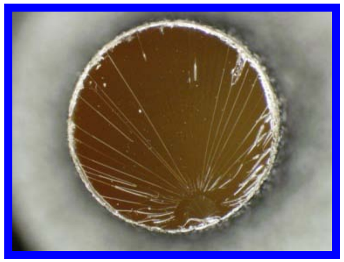
Growth of endotherm



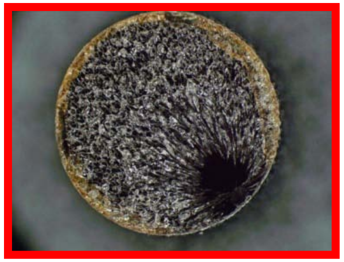
Resin tensile properties



Fracture surfaces



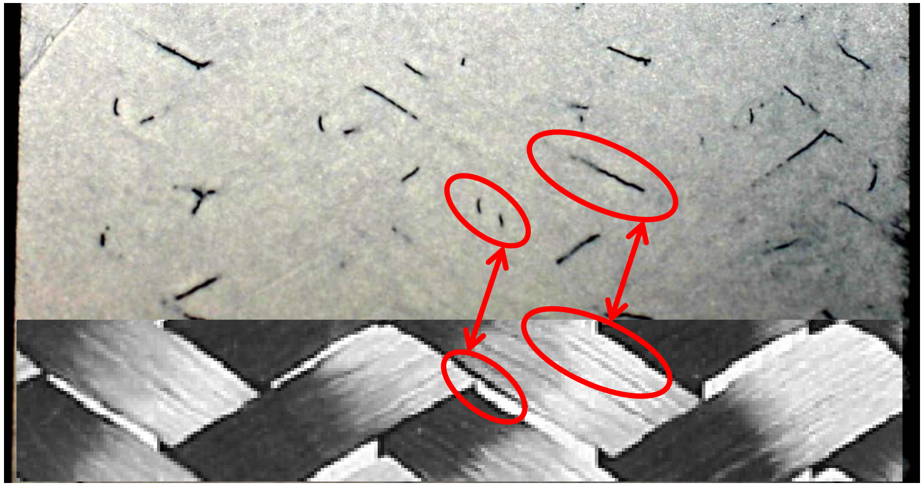
0 Cycles



54 Cycles

108 Cycles

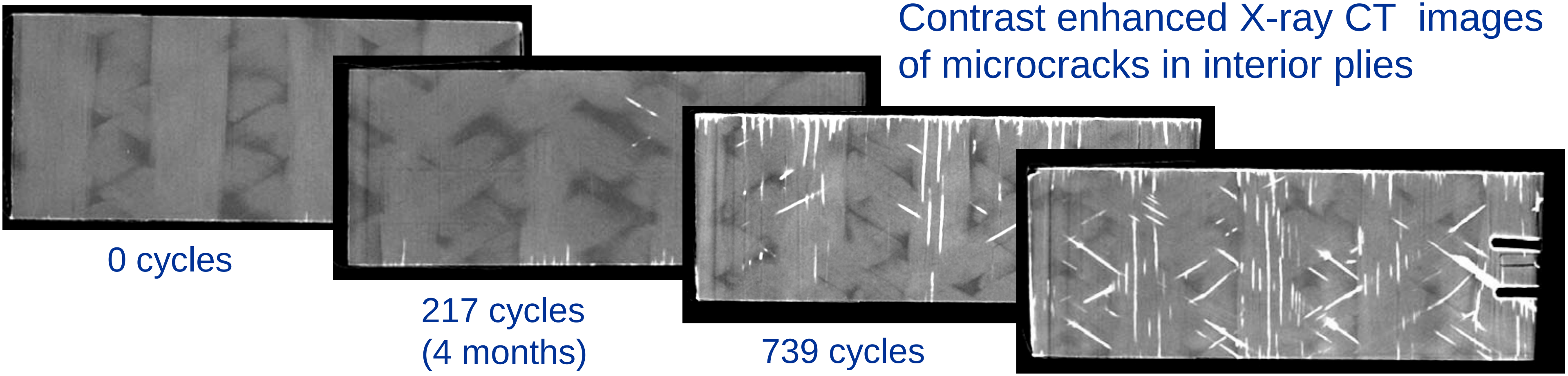
Composite microcracking



Microcracks visible on a painted surface

Overlaid image of braid architecture showing crack locations within fiber tows

Contrast enhanced X-ray CT images of microcracks in interior plies



0 cycles

217 cycles (4 months)

739 cycles (12 months)

739 cycles – different ply (12 months)

Composite mechanical property test methods

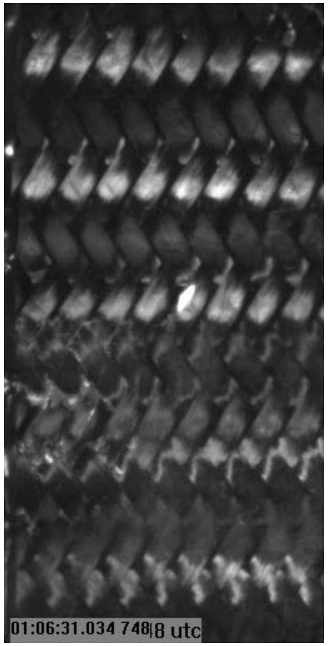
ASTM D 3039 Tension

ASTM D 3410 Compression

Modified V-Notch Rail Shear (in progress)

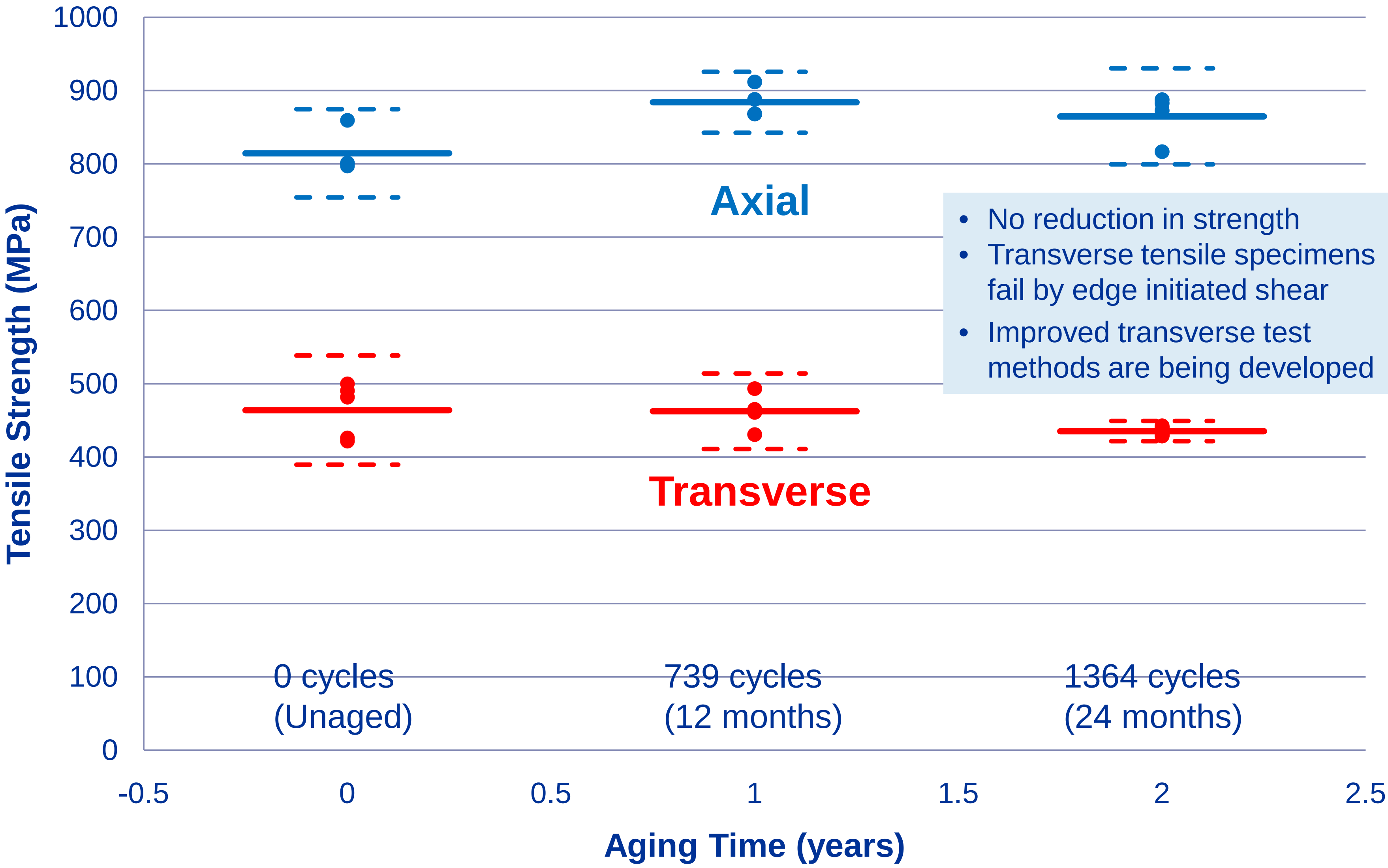
Test plan limitations

- The number of tests per aging condition was limited by material availability
- The ASTM D 3039 test method does not provide an accurate measure of transverse tensile strength for braided composites
  - Used only to provide an indication of aging effects
  - Improved test methods are being developed



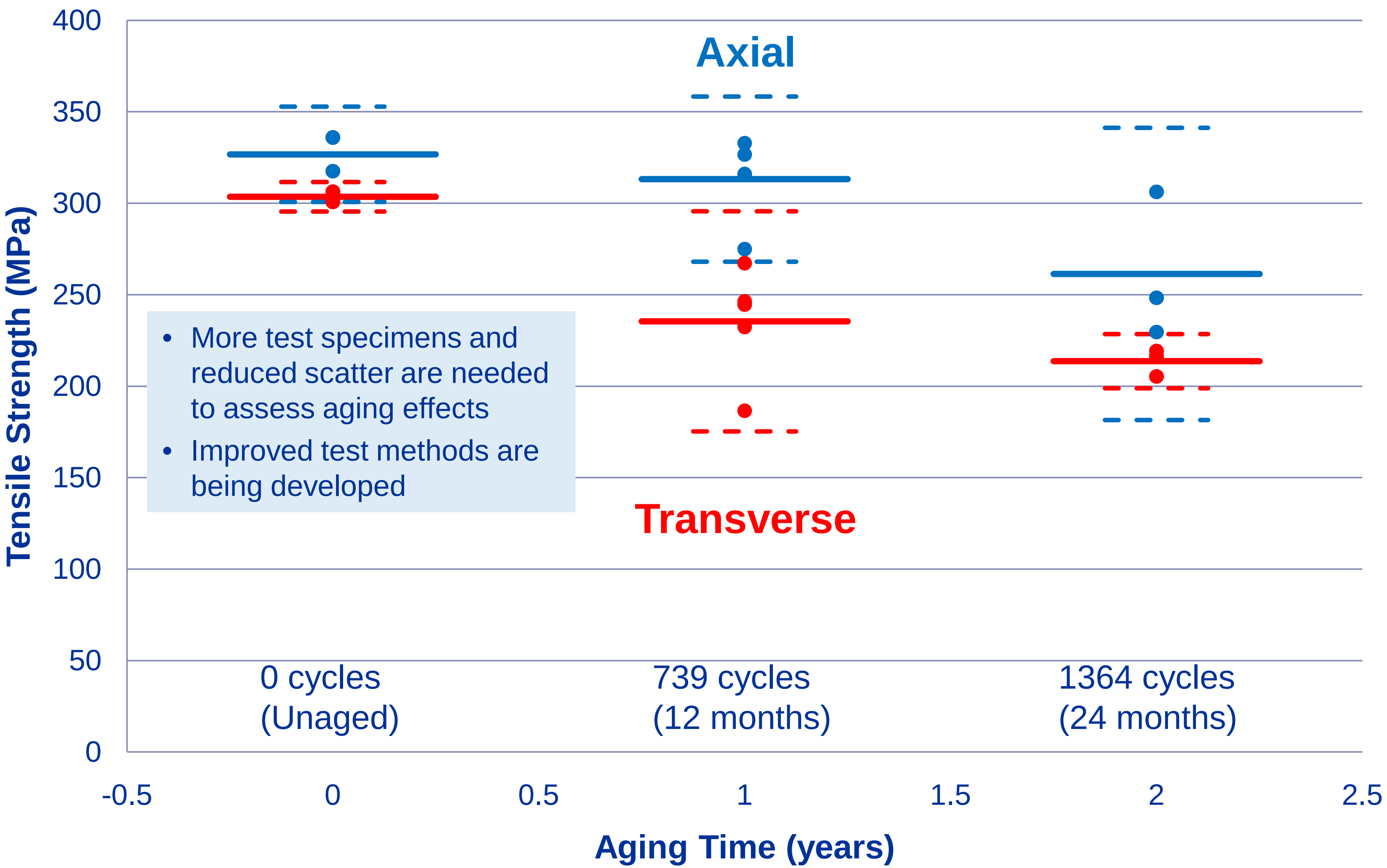
Edge initiated shear failure in a transverse tensile specimen

Tensile Strength

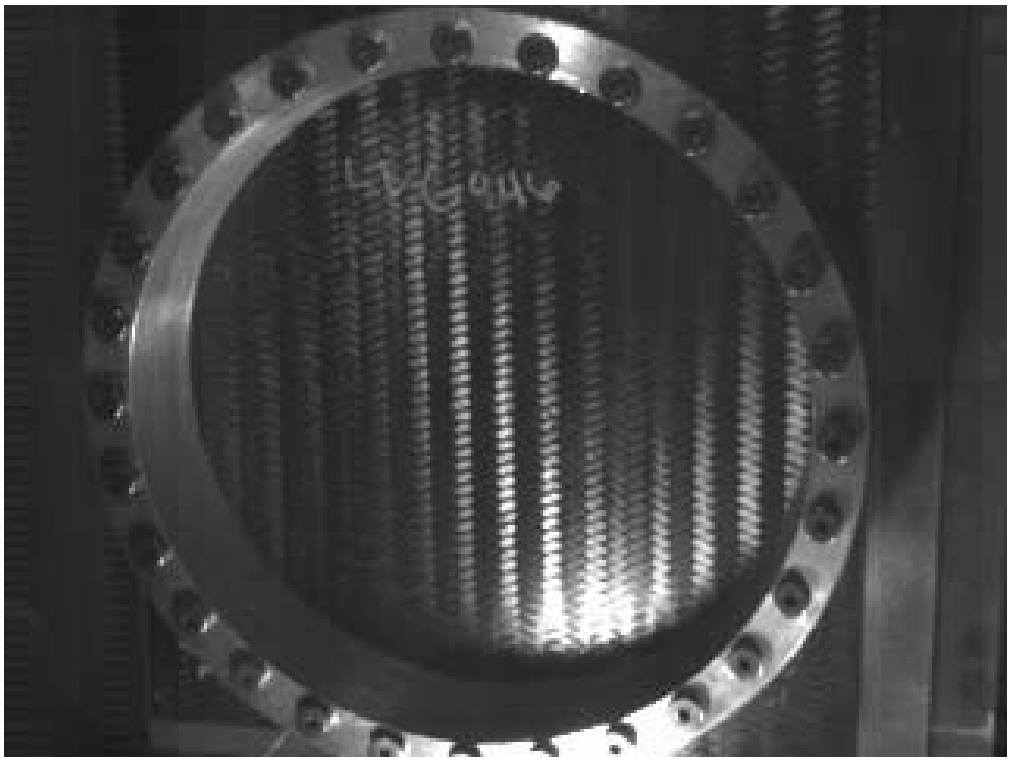


- No reduction in strength
- Transverse tensile specimens fail by edge initiated shear
- Improved transverse test methods are being developed

Compression Strength

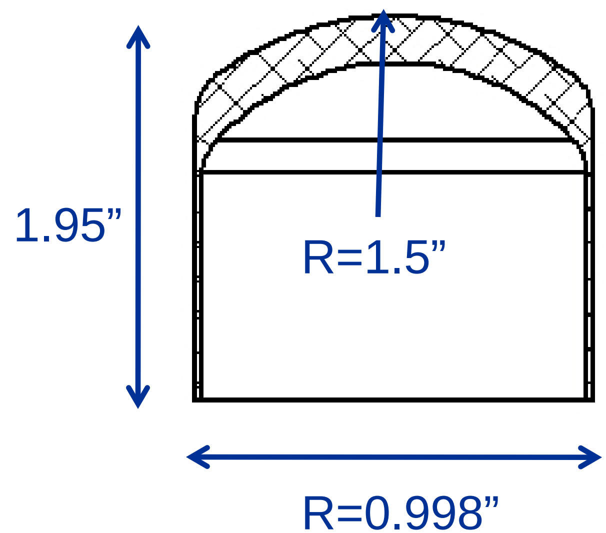


Ballistic impact test method

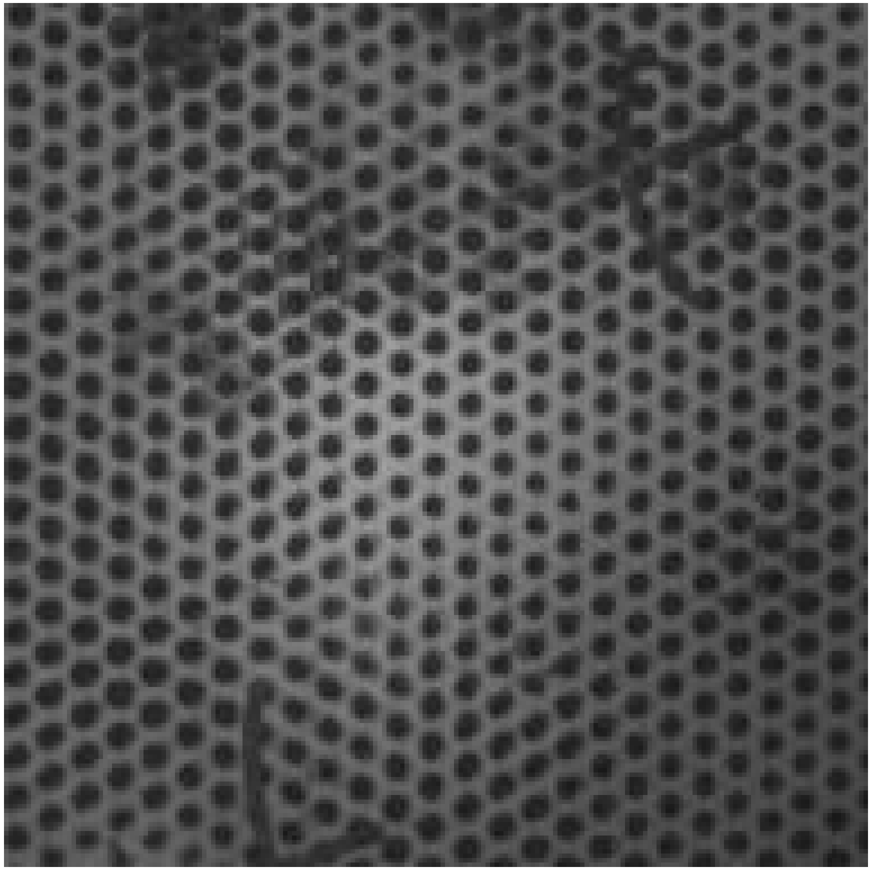
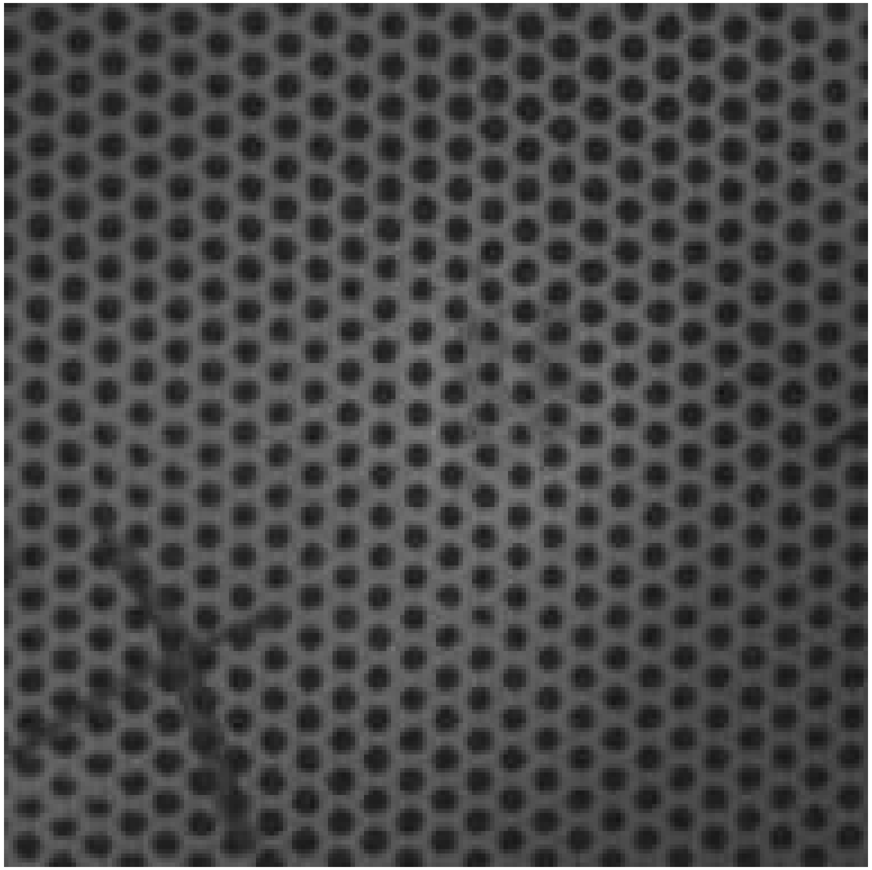


Test method considerations

- Blunt impact allows large deformation before failure
- Simple method enables easier use in other labs
- 12 in X 12 in panel size provides efficient use of material

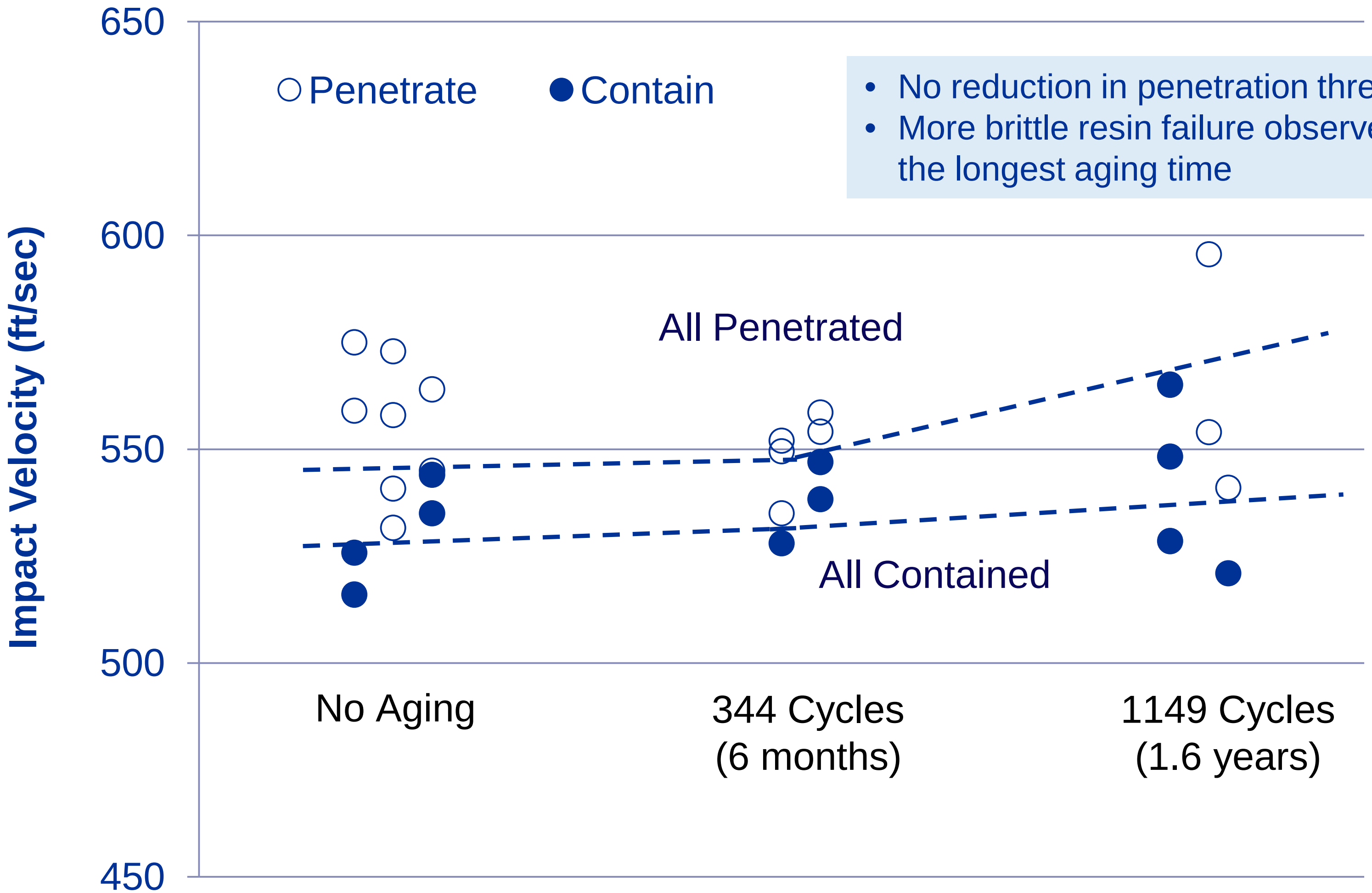


Example of ballistic impact penetration threshold

Contained	Penetrated
	
526 ft/sec	541 ft/sec

Ballistic impact results

- No reduction in penetration threshold
- More brittle resin failure observed for the longest aging time



Conclusions

- Chemical changes in the resin material were confined to a region within 0.2 mm of the surface
- Densification (volume loss) occurred during early cycles and remained constant during later cycles
- Resin embrittlement occurred during early cycles and seemed to be correlated with densification
- Microcracking occurred in both surface and interior plies, particularly at the longer aging times
- Aging did not cause a reduction in tensile strength
- The effect of aging on compressive strength could not be determined because of limited test specimens and large scatter in the data
- Aging did not cause a reduction in impact strength, although a more brittle resin failure mode was observed